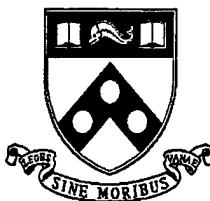


UNIVERSITY of PENNSYLVANIA



ELECTRICAL ENGINEERING DEPARTMENT

17-th Quarterly Report

**BIOMORPHIC NETWORKS FOR ATR AND
HIGHER-LEVEL PROCESSING**

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During the period of this report work progressed on the design and implementation in analog hardware of a parametrically modulated logistic processing element for use in the construction of fast analog Parametrically Coupled Logistic Map Networks. The design is based on a periodically driven spiking neuron circuit.

In preceding work we put forth the hypothesis that the basic functional unit in the cortex is not the single neuron but is the neuronal assembly or netlet and that the behavior of a netlet can be mathematically modeled by a parametrically modulated logistic map, a nonlinear iterative mapping on the unit interval. We also presented evidence of the utility of such processing elements in the modeling of cortical networks and introduced a new family of networks which we named Parametrically Coupled Logistic Map Networks (abbreviated PCLMNs) that are increasingly appearing to be key to efficient simulation and study of higher-level functions performed by the cortex which is the seat of all higher-level brain functions. The advantages of developing the theoretical and practical foundations for such *Corticonic networks* should be obvious especially for the development of new generation of machines with brain-like intelligence that goes beyond the capabilities of present day neural and connectionist models.

The advantage of using maps to model the cortex is that the map captures the complexity and richness of the continuous-time dynamics of cortical tissue usually described in terms of a very large-number of coupled nonlinear first-order differential equations whose numerical simulation is computationally extensive and time consuming. In contrast the iterative and discrete-time nature of the dynamics of PCLMNs lends itself readily to efficient rapid numerical computations. Furthermore each of the N parametrically coupled logistic maps (PCLMs) forming a PCLMN of N processing elements, (PEs) represents a cortical module or netlet with tens of thousands of neurons. A PCLMN of N=100 PEs would therefore be functionally equivalent to a cortical patch of 10^5 to 10^6 neurons. PCLMNs may therefore constitute a breakthrough in the modeling of brain function because of this number efficiency and the high degree of abstraction of cortical organization and function that they incorporate.

As stated, because of their discrete-time dynamics PCLMNs have the advantage of easy simulation on digital computer. Most of our simulations to-date, of a network of a PCLMN of typically N=100 units, were carried out on a PC in reasonable but finite time. Therefore, during the period of this report we initiated a study of the feasibility of building PCLMNs in fast analog hardware to enable real-time operation. Specifically we studied the feasibility of implementing an arbitrary map on the unit interval in analog hardware. The results obtained so far are quite encouraging and show that this is possible. We find that a simple spiking circuit we used earlier to study spiking neuron dynamics can be made to synthesize a class of nonlinear iterative maps on the interval that include the logistic map, tent map, and sine-circle map by simply altering the waveform of a periodic modulation applied the resting potential (the extinction voltage) of the

spiking-neuron circuit. The advantage of such a design is that the nature of the PEs in a PCLMN employing such analog PEs can be altered at will to any form of desired map by simply changing the waveform of the periodic modulation applied to the resting potentials of the spiking neuron circuit.

Examples of the results obtained in analog synthesis of arbitrary maps so far are presented in the attached internal memo entitled: Analog Realization of Arbitrary Maps on the Interval. We believe this is the first successful implementation of arbitrary maps in analog hardware. The ability to program the nature of the map at will by altering the nature of its periodic driving signal paves the way for a new class of analog computers with bifurcation processing elements that are capable of altering their functional behavior depending on the nature of the input they receive, or in other words:, depending on the "meaning" of the input they receive. In the circuit developed, the input would be applied to the threshold voltage of the spiking neuron circuit, that of a programmable unijunction transistor neuron (PUTON) or one equivalent to it.

The state variable $X(n)$ of the maps described in the attached memo was obtained by measuring the modulu 2π phase of the periodic driving waveform at the instants of spiking of the PUTON circuit with the aid of an hp 5371A Frequency and Time Interval Analyzer. Work now is in progress to design a simple circuit to be added to the PUTON circuit to carry out the phase-measurement so that the output of the composite circuit would be an analog voltage, ranging between $[0,1]$, whose value represents the normalized modulu 2π value of $X(n) = \omega t_n$ where ω is the frequency of the periodic driving waveform and t_n $n=1,2,\dots$ is the instant of the n -th spike. With this addition we would have a complete programmable circuit of an arbitrary map on the interval with analog state-variable that can be used in the construction of corticonic networks suitable for the study of higher-level brain function. Such corticonic networks would ultimately find use in the learning and recognition of spatio-temporal signals of the kind encountered in NCTR, sonar, and other similar applications involving dynamic input patterns something that is presently outside the capabilities of present day neural net and connectionist models.

Activities:

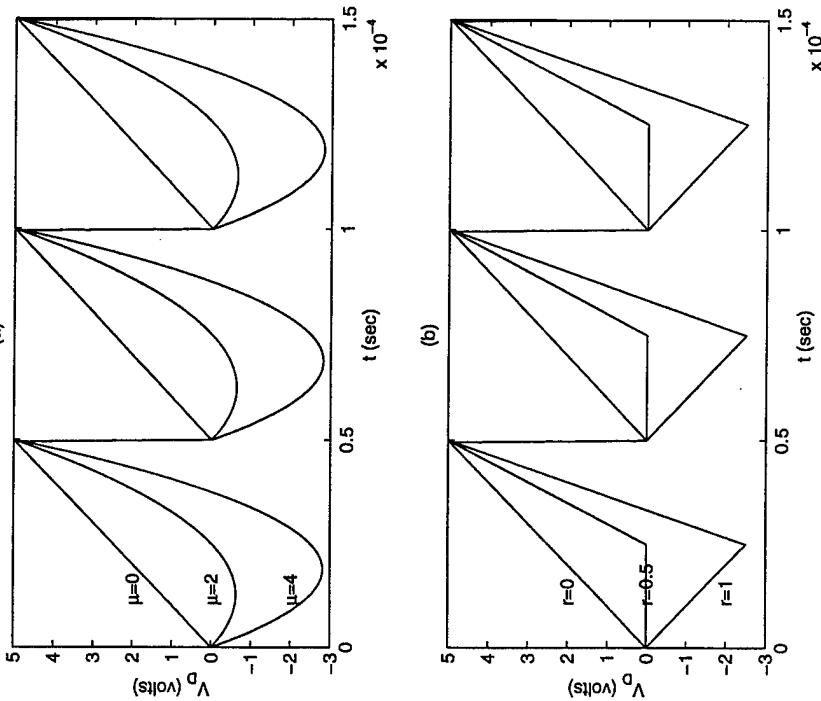
During this period, N. Farhat participated in the High Resolution Radar Techniques Symposium organized by the NATO SET Panel, held on March 22-24 in Granada, Spain. He presented a Poster Paper entitled: "Corticonic Systems for Higher-Level Processing and Radar Target Identification".

Analog Realization of Arbitrary Maps On the Interval

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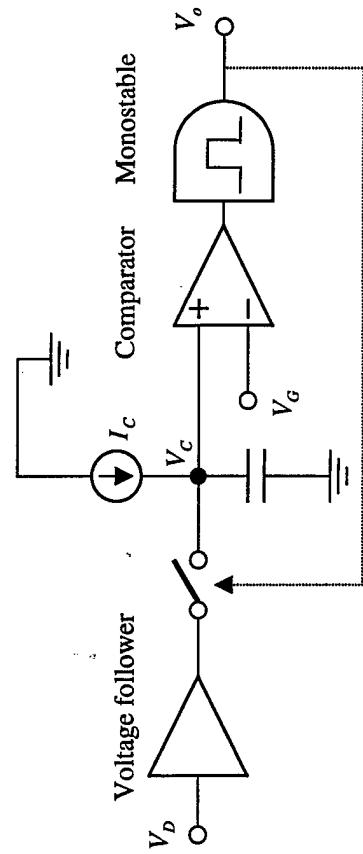
The driving waveforms for (a) the logistic map and (b) the tent map for three values of the control parameter in each.

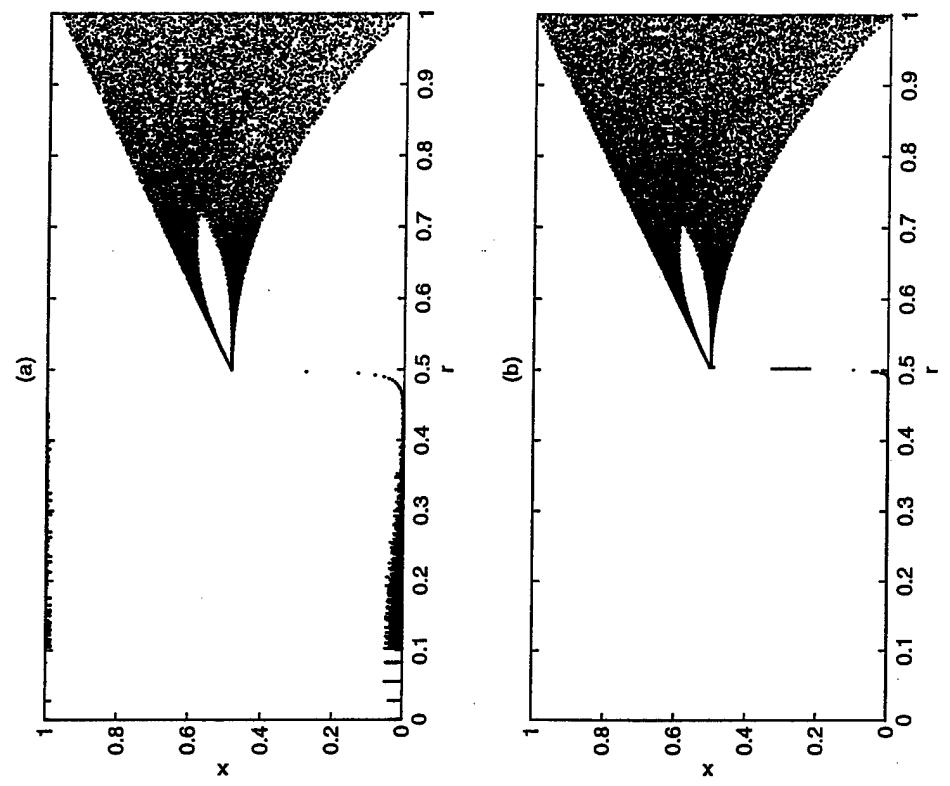
- 1-D Map to embed: $x_{n+1} = f(x_n)$
- 1-D Map to embed: $x_{n+1} = \left[\begin{cases} \frac{t}{T} - f\left(\frac{t}{T}\right) \\ V_D(t-T) \end{cases} \right] V_G, \quad 0 \leq t < T$
- Driving waveform: $V_D = \left[\begin{cases} \frac{t}{T} - f\left(\frac{t}{T}\right) \\ V_D(t-T) \end{cases} \right] V_G, \quad \text{otherwise}$



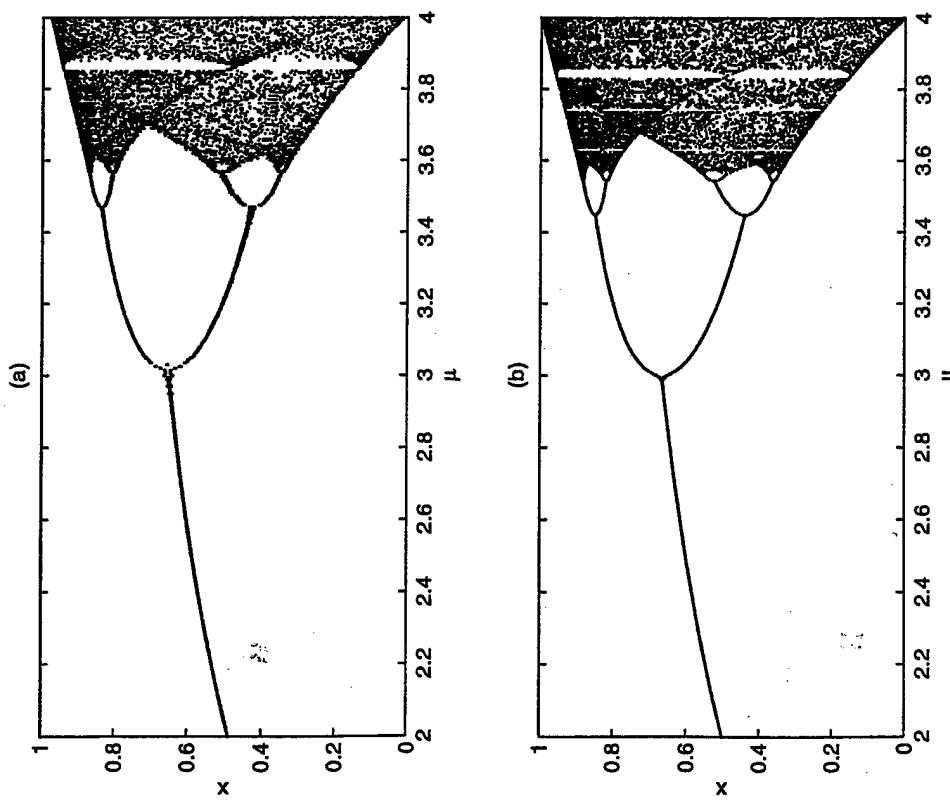
The Programmable Unijunction Transistor Oscillator Neuron (PUTON) was first introduced by Farhat and coworkers[1] as an integrate-and-fire model neuron. The initial investigation showed that the timing of successive spikes (firings) in the firing sequence it produces is related to the sine-circle map when it is subject to a sinusoidal driving signal representing correlations in the spike trains impinging on the neuronal dendrites. Based on this observation a novel scheme is developed to embed any 1-dimensional recursion defined on the unit interval in the firing time of the PUTON simply by changing the periodic driving signal waveform appropriately. The bifurcation diagrams of the sine-circle map, the logistic map and the tent map are measured experimentally from the programmed PUTON as verification of the validity of the new concepts of analog synthesis of arbitrary one-dimensional maps.

Skeletal equivalent circuit diagram to the PUTON.





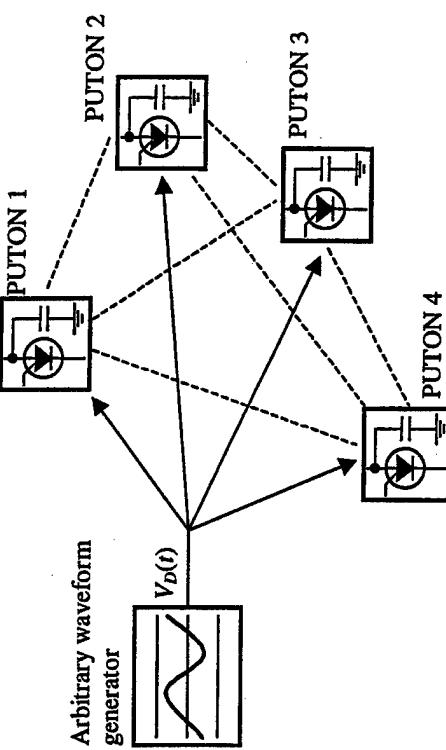
Bifurcation diagrams of tent map: $x_{n+1} = r(1-2|x/2-x_n|)$.
 (a) by measuring the spike times of the PUTON and (b) by evaluating the map numerically.



Bifurcation diagrams of logistic map: $x_{n+1} = \mu x_n (1-x_n)$,
 (a) by measuring the spike times of the PUTON and (b) by evaluating the map numerically.

Network of PUTONs As Programmable Analog Computer Based on Recursive Processing Elements

- The programmability of PUTON enables us to implement computation models based on different recursive processing elements by using essentially the same hardware.

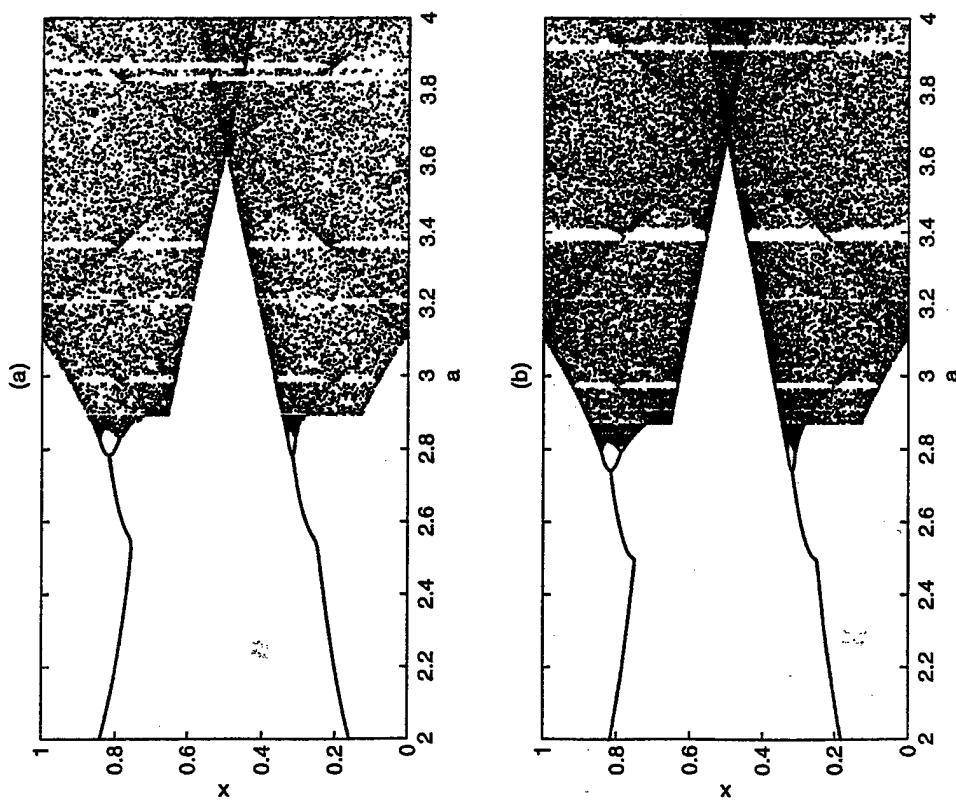


- The traditional ways of electronic computing use voltages and transfer functions, while the use of PUTON in an analog computers suggests the use of time and phase transition maps.
- Computational models employing recursive maps compute with diverse attractors and utilize synchronicity, bifurcation and chaos in their operation.

Reference:

[1] N. H. Farhat and M. Eldefrawy, "The Bifurcating Neuron: Characterization and Dynamics", Proceedings of SPIE 1773, pp. 23-34, 1993.

(a) by measuring the spike times of the PUTON and (b) by evaluating the map numerically.



Bifurcation diagrams of circle map: $x_{n+1} = x_n + \Omega - \frac{K}{2\pi} \sin 2\pi x_n$.

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